Survival and Growth of Trees of a Canaan Valley, West Virginia Seed Source in Relation to Varying Soil/Site Conditions

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Cover Photo: Variations in growth, form, and density of trees of West Virginia balsam fir growing on moderately well-drained (left) and somewhat poorly drained (right) sites in the same grower-owned plantation. The tree on the left had been sheared for four years, while the tree on the right had not been sheared.

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Introduction and Background

In research initiated at The Ohio State University's Ohio Agricultural Research and Development Center (OSU/OARDC) in the early 1970s, trees of balsam fir, from four different areas and planted on four sites having varying internal soil drainage characteristics, were compared (Brown, 1983). In that study, trees of the Canaan Valley, West Virginia source — "Canaan Fir" — *(Abies balsamea* var. *phanerolepis)*[1] had several characteristics that made them desirable for planting as Christmas trees, including: (1) they leafed out much later in the spring and were damaged less by spring frosts than trees of New York and Pennsylvania origins *(Abies balsamea* var. *balsamea)*[1] and were also less affected than were trees of Fraser fir from a North Carolina origin *(Abies balsamea* var. *fraseri)*[1]; (2) trees had more lateral limbs between the "annual whorls" than did trees of the other sources, giving them a fuller and more dense appearance; and (3) in those plantings having moderately well to somewhat poorly drained soils, trees of the West Virginia origins survived much better than did those of the North Carolina source; on the site having somewhat poorly drained soils, trees of the West Virginia origin did not survive as well as those of the New York and Pennsylvania origins.

At the conclusion of that study, the need was recognized for additional research to evaluate the adaptability of trees of the West Virginia source of balsam fir to a fuller range of soil/site conditions.

Methods

Two sets of plantings were used in the research. Trees in the first set were originally grown as part of an OSU/OARDC study at the Ohio Division of Forestry nursery at Marietta to investigate nursery practices (seedling density, shading, and age) needed to produce acceptable seedling stock for field planting. Cones had been collected by OSU/OARDC personnel in the fall of 1984 from a natural stand of balsam fir in Canaan Valley, West Virginia, and seed was planted in the nursery in the spring of 1985. Following termination of the study in the spring of 1989, seedlings were lifted from nursery beds and 225 trees were distributed to each of 22 Christmas tree growers in Ohio who had plantations representing a wide range of soil/site conditions. In addition, plantings were made at two OSU/OARDC sites.

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[1] For purposes of research reported here and in other studies at OSU/OARDC, the taxonomic classification of balsam fir proposed by Thor and Barnett (1974) has been used; this classification recognizes one species of *Abies* as occurring in eastern North America, with three varieties as indicated. A more complete review of studies related to the taxonomy of *Abies balsamea* can be found in OARDC Research Bulletin 1191, *West Virginia Seed Sources of Balsam Fir: Between- and Within-Stand Variation in Characteristics of Half-Sib Families and Individual Progeny* (Brown, 1999).

Figure 1. Location of plots sampled in the study of soil/site factors affecting survival and growth of a Canaan Valley seed source of balsam fir.

Preliminary analyses of data collected in those plantings indicated that trees on 35 of 63 plots had received annual applications of "residual" herbicides (which act, at least in part, through the roots of vegetation) for at least the first four years after trees were planted in combination with periodic mowings. On the other 28 plots, less effective types of weed control were used, including less frequent or no applications of residual herbicides, fall applications of foliar herbicides only, mowing only, etc., and on those plots it was difficult to assess the effects of other soil/site factors on survival, growth, and foliage characteristics of trees.

To provide additional data, plantings receiving "effective weed control" were needed which were of comparable seed source, size of planting stock, and years in the field after planting to that used in the original plantings. For that purpose, trees grown from seed collected in the Canaan Fir Tree Company's planted seed orchard in Canaan Valley and sold to 12 growers in Ohio (some of whom had plantings used in the first set of evaluations) as plugs+1 planting stock in the spring of 1990 were used. The seed orchard had been established in the early 1960s using trees grown from seed collected from natural stands in Canaan Valley. A total of 45 additional plots were established in those plantings, giving a total of 108 plots, 80 of which received "effective" chemical weed control (Figure 1).

Growers receiving trees for each set planted them in one or more blocks in their plantations and maintained them using various cultural practices, including weed control, fertilization, shearing, insect and disease control, and more.

Beginning in the winters of 1996-97 (for the first set of plantings) and 1997-98 (for the second set), a series of evaluations was made in the plantings. Since trees received by cooperators often had been planted over a relatively large area, two or more 10-tree plots having relatively uniform soil and other site factors within the plot were located in each plantation. Measurements and evaluations made on each plot included: (1) topographic factors; (2) a physical description of the soil and collection of soil samples from the A_p and B_2 horizons; (3) an evaluation of cultural practices (weed competition, weed control, and fertilization); (4) survival of trees; (5) measurements of total tree heights, four-year heights (height before shearing was started), and annual growth for the last three years; (6) needle lengths and retention; (7) needle color; and (8) collection of a composite foliage sample from trees (uniform length pieces from the upper one-third of the crown). In the laboratory, soil samples and foliage samples were prepared and analyzed, including: (1) soil textures using hydrometer analyses (Bouyoucos 1962); (2) chemical properties of soils (by the OARDC Research-Extension Analytical Laboratory — REAL); and (3) weight per piece of foliage samples (following oven drying). In September 1997 (for the first set) and 1998 (for the second set), foliage samples were collected from each plot, oven dried, and needles were ground and analyzed by REAL for nutrient content of foliage.

Means, standard deviations, and range in values were determined for all variables for plots with and without "effective" chemical weed control. Statistical correlation analyses were run to test relationships between tree characteristics (dependent variables) and all of the site factors (independent variables) measured. Based on those correlations, multiple regression analyses were made in an attempt to develop mathematical models that would relate various combinations of independent variables (topography, soils, foliar nutrients, and management) to various tree characteristics (survival, growth, and foliage characteristics).

Results and Discussion

A summary of means, standard deviations, and ranges in values for the tree, plantation management, topographic, soil, and foliar nutrient factors measured and evaluated in the study are presented in Table 1 for plots that received "effective" chemical weed control and those without such weed control. In addition, correlations between tree characteristics and various

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Table 1. Means, Standard Deviations, and Ranges in Measurements for Tree, Plantation Management, Topographic, Soil, and Foliar Variables Measured in the Study.

Variable	"Other" Weed Control[1]				"Effective" Weed Control[1]			
			Range				Range	
	Mean	S.D.	From	To	Mean	S.D.	From	To
Tree Survival, Growth, and Foliage Characteristics								
Plot Survival, %	73.1	20.3	25	100	86.9	18.9	16	100
Total Tree Ht., m	1.20	0.41	0.46	1.92	1.75	0.33	0.82	2.41
4-Yr. Tree Ht., m	0.61	0.25	0.33	0.94	0.91	0.22	0.42	1.40
Needle Length, mm	17.2	2.9	10	23	19.1	2.8	13	27
Foliage Color[2]	3.1	0.5	2.0	4.0	3.4	0.5	2.2	4.2
Foliage Weight, gms[3]	1.41	0.27	0.70	1.90	1.57	0.25	1.01	2.22
Lateral Limbs, no.	11.8	5.1	3	23	16.4	4.4	4	30
Needle Retention, yrs.	3.18	0.48	2.3	4.0	3.43	0.52	2.4	4.4
Plantation Management								
Type Weed Control[4]	2.5	0.8	1.0	3.0	1.0	0.0	1.0	1.0
Vegetation Density[5]	3.7	0.8	3.0	4.0	2.0	0.5	1.5	4.0
Effectiveness Weed Cont.[6]	3.6	1.0	3.0	4.0	1.6	0.5	1.0	2.5
Topographic Factors								
Azimuth, deg.	175	105	5	350	182	108	5	330
Slope, %	8.3	7.2	2	29	7.7	7.2	1	26
Plot Dist. from Ridge, %	50	28	0	100	52	27	0	100
Slope Shape[7]	1.9	0.7	1	3	1.8	0.7	1	3
Soil Physical Factors								
Total Depth, in.	34.2	4.4	26	36+	33.8	4.6	22	36+
Depth Mottling, in.	18.7	11.1	0	36+	17.8	10.3	0	36+
Thickness A_p, in.	5.6	2.0	1	9	7.0	1.9	2	10
A Horizon Sand, %	30.1	16.3	4	51	31.2	17.4	1	82
A Horizon Clay, %	23.8	7.9	14	52	22.7	7.2	6	40
B Horizon Sand, %	29.4	15.8	2	57	31.5	15.4	5	57
B Horizon Clay, %	31.1	9.5	18	61	27.9	7.4	10	61
Soil Chemical Factors								
A Horizon pH	5.71	0.63	4.5	6.6	5.61	0.64	4.4	6.6
A Horizon Lime Test Index	64.9	3.49	58	70	65.7	3.41	55	70

Table 1 (continued). **Means, Standard Deviations, and Ranges in Measurements for Tree, Plantation Management, Topographic, Soil, and Foliar Variables Measured in the Study.**

Variable	"Other" Weed Control[1]				"Effective" Weed Control[1]			
			Range				Range	
	Mean	S.D.	From	To	Mean	S.D.	From	To
A Horizon P, lbs/ac	52.2	49.4	2	142	59.0	50.2	8	198
A Horizon K, lbs/ac	208	81.6	90	418	198	82.8	72	450
A Horizon Ca, lbs/ac	1,840	1,080	480	6,860	1,710	1,052	250	6,140
A Horizon Mg, lbs/ac	260	167.2	62	642	277	167.0	50	800
A Horizon Cat. Ex. Cap.	12.3	3.8	8	22	10.8	3.4	5	21
B Horizon pH	5.38	0.60	4.6	6.3	5.44	0.63	4.3	7.2
B Horizon Lime Test Index	64.8	3.40	54	70	66.9	2.90	60	70
B Horizon P, lbs/ac	17.0	30.8	2	160	18.2	31.0	2	198
B Horizon K, lbs/ac	170	63.2	70	382	171	60.2	60	368
B Horizon Ca, lbs/ac	2,610	880	260	4,680	2,073	940	250	4,420
B Horizon Mg, lbs/ac	410	223	112	1,210	383	210	50	1,210
B Horizon Cat. Ex. Cap.	11.7	5.6	6	38	10.6	4.0	3	19
Foliar Element Levels								
Nitrogen, %	1.69	0.29	1.08	2.41	1.85	0.28	1.00	2.41
Phosphorus, %	0.19	0.04	0.14	0.29	0.22	0.04	0.14	0.33
Potassium, %	0.73	0.15	0.47	0.87	0.83	0.16	0.52	1.16
Calcium, %	0.53	0.16	0.43	0.98	0.59	0.16	0.23	1.15
Magnesium, %	0.12	0.02	0.10	0.19	0.14	0.02	0.09	0.20
Manganese, ppm	246	118	15	403	322	128	40	583
Iron, ppm	37	13.5	20	51	49	13.2	20	99
Boron, ppm	31	6.6	19	45	33	6.8	17	54
Copper, ppm	4.16	1.11	3.0	7.9	3.96	1.09	2.0	8.5
Zinc, ppm	29	12.5	13	43	39	12.8	16	75
Aluminum, ppm	211	176	70	503	261	189	18	999
Sodium, ppm	2.60	0.31	2.50	4.30	2.51	0.13	1.70	3.00

[1] Weed Control: "Effective" = annual applications of "residual" herbicides for at least the first four years; "Other" = methods of weed control other than that defined as "effective."

[2] Foliage Color Rating: 1 = Yellow; 2 = Green/Yellow; 3 = Yellow-Green; 4 = Green; 5 = Blue/Green.

[3] Foliage Weight: Average weight of a four-inch long foliage sample from the upper one-third of the tree.

[4] Type Weed Control: 1 = Annual Chemical; 2 = Occasional Chemical; 3 = Mowing Only.

[5] Vegetation Density: 1 = Bare; 2 = Light; 3 = Medium; 4 = Dense.

[6] Effectiveness of Weed Control: 1 = Excellent; 2 = Good; 3 = Fair; 4 = Poor.

[7] Slope Shape: 1 = Concave; 2 = Flat/Even; 3 = Convex.

site factors for plots receiving "effective" chemical weed control are given in Table 2.

Influence of "Effective" Chemical Weed Control

As noted earlier, the initial plantings made in 1989 contained (1) plots which received "residual" herbicide applications for at least the first four years after planting (in combination with periodic mowing) and (2) other combinations of weed control, including occasional use of herbicides and/or mowing. Analyses of data from those plots indicated that in the absence of "effective" chemical weed control it was difficult to assess relationships between performance and appearance of trees and other management, topographic, soil, and foliar nutrient variables (Figure 2).

Because of the type of sampling system used in the study, direct statistical comparisons could not be made between the 80 plots that received "effective" chemical weed control and the 28 plots that did not receive such control. As shown in Table 1, means, standard deviations, and ranges in values for topographic, soil physical, and soil chemical factors sampled on plots with and without "effective" weed control were generally similar. However, values for tree characteristics, plantation management variables, and foliar nutrient levels were very different.

For plots receiving effective chemical weed control, the average rating for vegetation density was 2.0 (light) and 1.6 (excellent/good) for weed-control effectiveness, while for plots without such control, averages were 3.7 (near the dense rating) and 3.6 (fair/poor), respectively. Effects of vegetative competition on growth and foliage characteristics were pronounced. On plots having effective weed control, survival of trees averaged approximately 14 percent higher than on plots that did not receive such control, while total tree heights and four-year heights averaged more than 45 percent higher; in addition all foliage characteristics of trees were eight to 11 percent higher for trees with effective weed control. Similar effects of weed control on survival, growth, and/or foliage characteristics of trees in plantations have been noted in a number of other studies (Brown, 1980 and 2000; Brown *et al.*, 1989; Heiligmann *et al.*, 1985). Also, levels of all elements in the foliage except copper and sodium were higher, with N, P, K, Ca, and Mg being nine to 17 percent higher and micronutrient levels six to 34 percent higher.

Because of the "masking" effects of vegetative competition on plots on other site factors, only those plots that had effective weed control were used in the following discussions of the overall performance of trees and in correlation and regression analyses to look at specific relationships between tree and site factors.

Averages and Ranges in Survival, Growth, and Foliage Characteristics of Trees

Survival: As shown in Table 1, survival of trees on the 80 study plots having effective weed control averaged 86.9 percent for all plots, with a range of 16 to 100 percent. In individual plantings, there were areas where survival was 0, and those areas were usually associated with "very wet" conditions, particularly fine textured soils with poor internal soil drainage in combination with concave-shaped surfaces. Conversely, best growth of trees was most often associated with well to moderately well-drained, loam to silt-loam textured soils.

Height Growth: After seven growing seasons in the field, total heights of trees averaged 1.75 m (6.5 ft) for all plots, while for individual plots, the range was from 0.82 to 2.41 m (2.7 to 7.9 ft); there were individual trees within plots as small as 0.50 m (1.6 ft) and as tall as 3.00 m (9.8 ft). From these figures, it is apparent that the average total height for all trees in the study, after seven growing seasons, was at or near marketable size, while some trees could have been harvested after not more than six years. The slowest-growing trees on plots were usually associated with lower survival rates and with conditions similar to those noted for poor survival.

Table 2. Simple Correlations Between Tree Measurements and Site Factors for Plots Receiving "Effective" Chemical Weed Control.

Site Factors[6]	Plot Surv.	Tot. Ht.	4-Yr. Ht.	Ndl. Lng.	Ndl. Ret.	Fol. Clr.	Fol. Wt.
	Simple Correlation Coefficient, r						
Topographic Factors							
Plot Slope %	0.14[1]	0.23[3]	0.23[3]	0.44[5]	0.24[3]	0.19[2]	0.14[1]
Plot Slope Shape	0.23[3]	0.20[2]	0.24[3]	0.09[1]	0.16[1]	0.30[4]	0.08[1]
Soil Physical Factors							
Depth to Mottling	0.37[5]	0.43[5]	0.27[3]	0.60[5]	-0.19[2]	0.19[2]	0.41[5]
Thick A_p Horizon	0.11[1]	0.07[1]	0.01[1]	-0.04[1]	0.19[2]	0.20[2]	0.02[1]
A Horizon, Sand.	0.19[2]	0.34[4]	0.41[5]	0.15[1]	0.34[4]	0.17[1]	0.19[2]
A Horizon, Clay	-0.02[1]	-0.23[3]	-0.15[1]	-0.19[2]	-0.35[5]	0.09[1]	0.14[1]
B Horizon, Sand	0.14[1]	0.30[4]	0.34[4]	0.23[3]	0.31[4]	0.09[1]	0.24[3]
B Horizon, Clay	-0.03[1]	-0.27[3]	-0.19[2]	-0.28[3]	-0.38[5]	0.08[1]	-0.09[1]
Soil Chemical Factors							
A Horizon, Phosphorus	0.04[1]	0.23[3]	0.23[3]	0.24[3]	-0.06[1]	0.09[1]	0.12[1]
A Horizon, Calcium	-0.16[1]	-0.24[3]	-0.24[3]	-0.13[1]	-0.03[1]	-0.11[1]	-0.12[1]
A Horizon, Magnesium	-0.20[2]	-0.21[2]	-0.10[1]	-0.25[3]	-0.19[2]	-0.09[1]	-0.01[1]
Foliar Element Levels							
Nitrogen	0.17[1]	0.35[5]	0.16[1]	0.59[5]	0.20[2]	0.31[4]	0.37[5]
Potassium	0.28[3]	0.60[5]	0.57[5]	0.35[5]	0.39[5]	0.60[5]	0.22[3]
Calcium	0.06[1]	0.28[3]	0.11[1]	0.34[4]	0.21[2]	0.04[1]	0.25[3]

[1] Not statistically significant.
[2] Statistically significant at 10 percent probability level.
[3] Statistically significant at 5 percent probability level.
[4] Statistically significant at 1 percent probability level.
[5] Statistically significant at 0.1 percent probability level.
[6] Only those variables for which correlations were statistically significant with one or more tree characteristics are included.

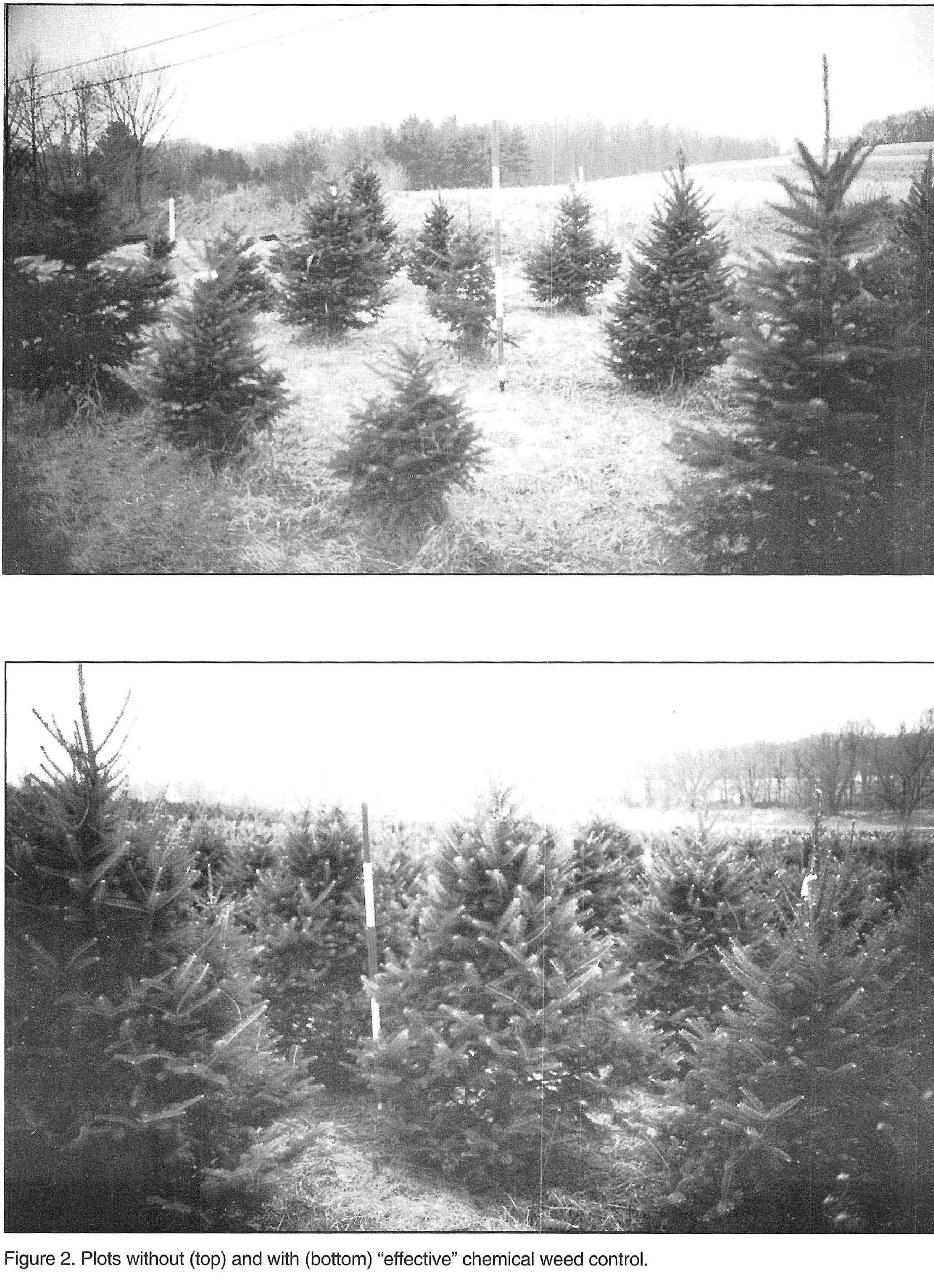

Figure 2. Plots without (top) and with (bottom) "effective" chemical weed control.

In plots where growth was good, trees had been sheared at varying intensities for two or more years, so comparisons between total heights may not be completely reflective of site and management conditions. To provide a more common basis for comparison, heights after four growing seasons in the field (four-year heights) were also measured, with trees averaging 0.91 m (3.0 ft) and a range in averages for individual plots from 0.42 to 1.40 m (1.4 to 4.6 ft). For individual trees in plots, four-year heights ranged from 0.29 to 1.68 m (1.0 to 5.5 ft).

Needle Lengths: Needle lengths of trees also varied greatly on plots, with an average of 19.1 mm (0.75 in) and a range of 13 to 27 mm (0.5 to 1.1 in), approximately the same as that noted for needle lengths in a study of variation between half-sib progeny of different West Virginia balsam fir seed sources (Brown, 1999).

Foliage Color: Evaluations of the color of the upper surface of needles showed an average rating for all plots of 3.4 — yellow/green to green. Ratings for individual plots were as low as 2.2 —green/yellow (with individual trees at the yellow rating) and as high as 4.2 — green (with many individual trees at or above the blue/green rating). Almost invariably, the poorest color occurred on plots having "wetter" soils.

Foliage Weights: Other studies conducted by the author have found that comparative weights of uniform pieces of foliage can be a good indicator of overall growth and vigor of Christmas trees growing under varying conditions or receiving different experimental treatments (fertilization, weed control, etc.). For trees sampled in this study, there was a wide range in foliage weights, with an average of 1.6 grams per four-inch piece and a range of 1.0 to 2.2 grams for individual plots. Again, the lowest values were generally found on "wetter" sites.

Numbers of Lateral Limbs: During the study, lateral limb counts were made on terminal shoots that had developed in 1994 or 1995. For all plots, the average number was 16.4, with an eight-fold range (4 to 30) on individual plots. Lower counts were invariably on some of the slowest-growing trees having 1994/1995 terminals which averaged as low as one inch in length. The numbers of laterals per unit length of terminal shoot averaged 1.7 per inch, with a range of 1.0 to 3.0 per inch, with no apparent relationship to varying site and management factors.

Needle Retention: The number of years that needles were retained on lateral limbs varied considerably for trees on plots, averaging 3.43, with a range of 2.4 to 4.4 years, and some individual trees having needles only on the most recent shoot growth. As noted for other characteristics, poorest needle retention was usually associated with conditions where survival and growth were poorest and particularly on "wetter" soils.

Topographic Factors

In soil/site studies with forest stands in Ohio, the author has found that indirect effects of topographic factors on growth of trees can be very substantial, particularly on the upper portions of steeper areas having southwest-facing slopes (Brown and Stires, 1984; Brown and Marquard, 1988; Brown and Duncan, 1990). As indicated in Table 1, the average percent distance to ridge (slope position) for plots was at approximately mid-slope with a distribution of plots from ridge (0 percent) to bottomland (100 percent positions). Although there were some plots on steeper areas (maximum slope of 26 percent), surface topography of study plots can be characterized generally as gently sloping to flat, averaging 7.7 percent. Under those conditions, effects of azimuth/aspect (direction an area faces) is usually minimal, and this is reflected in the fact that there were no significant correlations between azimuth and any of the individual tree characteristics evaluated (Table 2). However, within individual plantings there were some graphic illustrations of the effects of azimuth (Figure 3) and slope position (Figure 4).

For slope percent, there were relatively small but statistically significant correlations with

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Figure 3. Plots located on southwest- (top) and northeast-facing (bottom) slopes in the same grower-owned plantation.

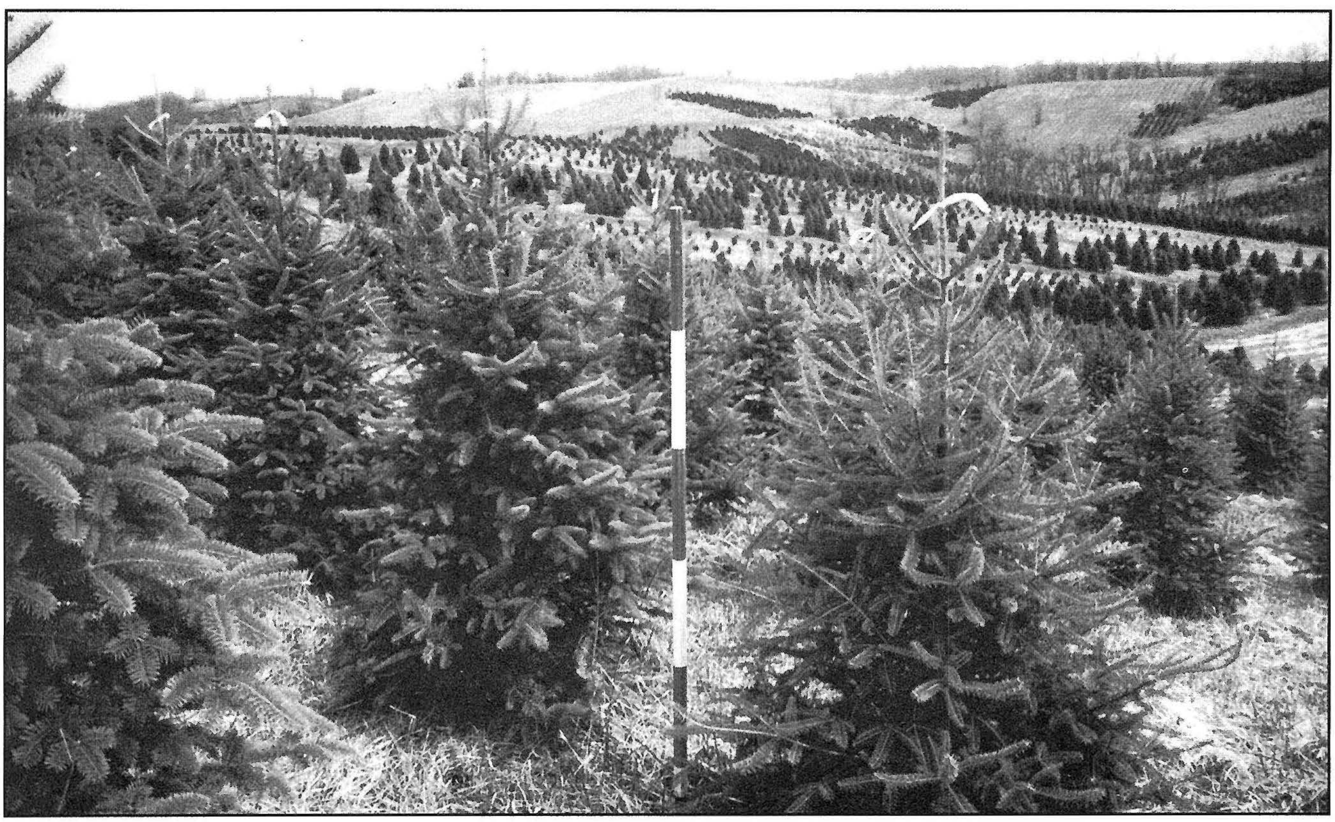

Figure 4. Plots located on upper- (top) and lower-slope (bottom) positions in the same grower-owned plantation.

five of the seven tree characteristics; however, all of those relationships are positive, indicating that tree growth and foliage characteristics improve as slope percent increases (Table 2). This is opposite of what has been commonly found in other soil/site studies in Ohio and is probably reflective of the generally low slope percents on plots where increased surface and subsurface runoff of precipitation could improve soil aeration for sites having the relatively fine textured soils which were characteristic on many of the plots sampled (Tables 1 and 2). However, there were noticeable effects on growth and other tree characteristics in plantings where there were was a wide range in slope percents (Figure 5).

Slope shape — whether it is concave, even/flat, or convex shaped — can have a major indirect topographic influence on survival and tree performance, and effects may be different depending on other topographic/soil factor combinations. On coarser-textured soils and/or drier upland positions, concave-shaped surfaces can have beneficial effects by helping collect or slow down surface runoff of precipitation; however, in bottomland areas or with finer textured soils, collection of water in concave-shaped areas can keep soils saturated to the point were survival and growth can be seriously affected. For the 80 plots in this study, the average slope shape, 1.8, was near the flat/even rating, with approximately equal numbers of plots having concave (1) and convex (3) configurations (Table 1); however, the concave-shaped plots often occurred in bottomland positions and often with finer-textured soils. As a result, there were relatively small but statistically significant correlations which indicated that survival, height growth, and foliage color were better on plots having flat/even to convex-shaped surfaces where surface runoff would be greater (Table 2, Figure 6).

Soil Physical Factors

Total Soil Depth, Depth to Mottling, and Thickness of the A_p Horizon: Total soil depth can be characterized as being deep, with the average (34 inches) near the maximum of 36 inches for which soil descriptions were made (Table 1), and there were no significant correlations with tree characteristics (Table 2). Average depth to mottling was also relatively deep, 18 inches, with a range of 0 to 36+ inches; of the 80 plots sampled, 27 percent showed no evidence of mottling within the 36-inch depth examined, 18 percent had mottling between 21 and 36 inches, 29 percent between 11 and 20 inches, and 26 percent within the upper 10 inches of the soil. With this preponderance of "moderately wet to wet" soils, there were significant, positive correlations, indicating that all tree characteristics improved as depth to mottling increased (Table 2, Figure 7). However, because of the influence of those "moderately wet to wet" soils, results of the study may not be as reflective of survival, growth, and foliage characteristics of trees growing on well-drained upland sites, particularly those where topographic influences might be stronger.

All study plots showed evidence of an A_p soil horizon, with an average thickness of 7.7 inches and a range from 2 to 10 inches (Table 1); only two tree characteristics, needle length and foliage color, showed significant (positive) correlations with thickness of the A_p horizon, and those were small (Table 2).

Soil Textures: Average soil texture (with percents sand and clay indicated in Table 1) on study plots would be a loam/silt loam for the Ap horizon and clay loam for the B_2 horizon. For individual plots, textures ranged from sandy loams to silty clays for the Ap and sandy loams to clays for the B_2 horizons; a high proportion of plots had clay percentages in the B_2 horizon that would put clay or some combination of clay in the textural designation. This relatively high clay content, coupled with seasonally high water tables and/or concave-shaped surface configurations, is probably largely responsible for the high proportion of plots showing mottling in the soil profile. As shown in Table 2, there were significant correlations between most of the tree characteristics evaluated and soil textures, with individual characteristics being better where sand contents of the A_p and B_2 horizons were higher and clay contents lower (Figure 8). As noted earlier, in bottomland areas, the effects of concave-shaped

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Figure 5. Plots located on steep (top, 22%) and moderate (bottom, 7%) slopes in the same grower-owned plantation.

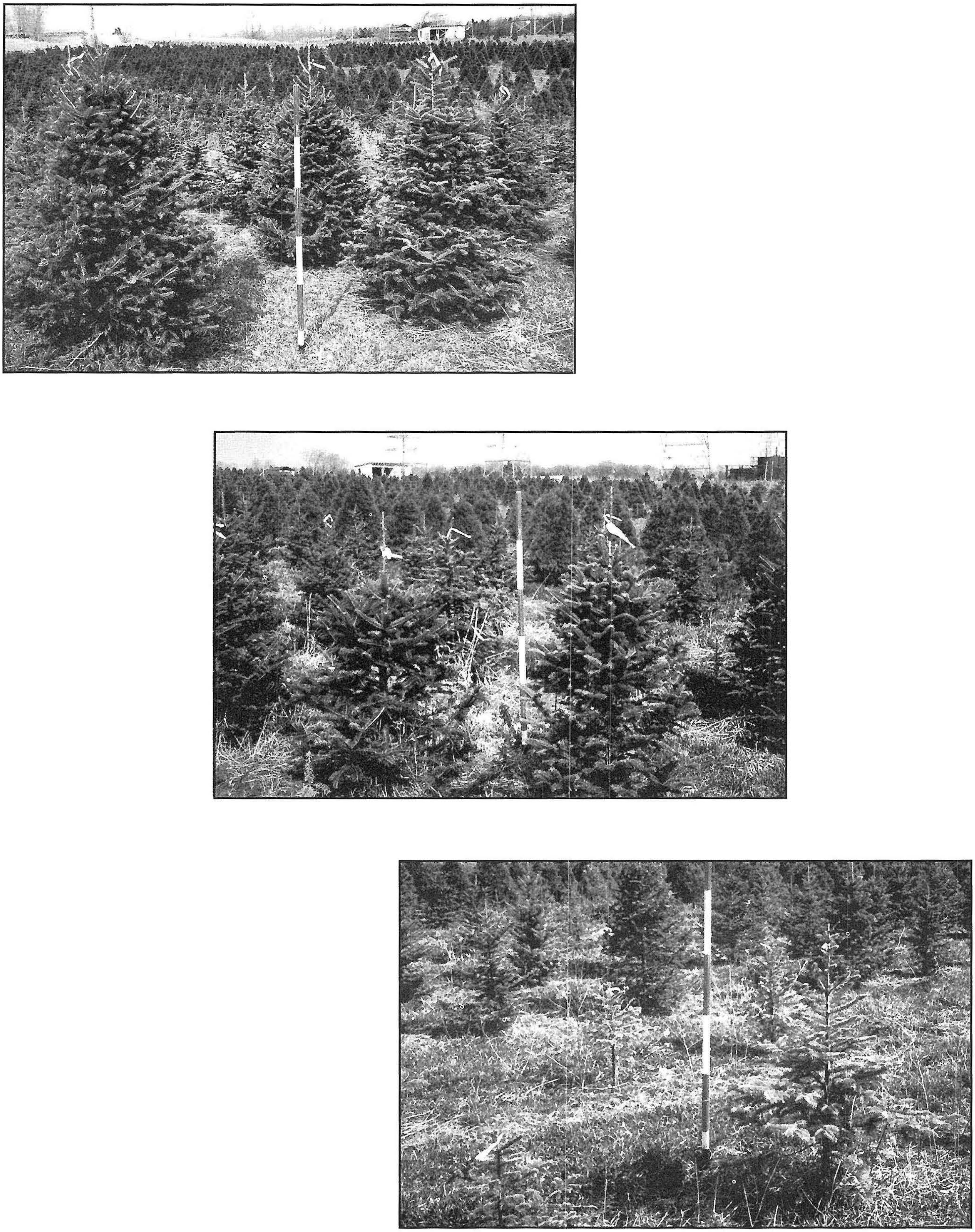

Figure 6. Effects of slope shape on fine-textured soils in the same grower-owned plantation. Top: Convex-shaped area, depth to mottling 10"; middle: flat/even-shaped area, depth to mottling 3"; bottom: concave-shaped area, mottling at surface.

Figure 7. Effects of depth to mottling in silty clay loam textured soils having flat/even surface configurations. Top, 30"; middle, 16"; bottom, 9".

Figure 8. Effects of slope shape on coarse-textured soils in same grower-owned plantation. Top: Convex-shaped area, depth to mottling 18"; middle: flat/even-shaped area, depth to mottling 13"; bottom: concave-shaped area, depth to mottling 8".

Figure 9. Effects of soil texture on concave-shaped areas in the same grower-owned plantation. Top: Silt loam, depth to mottling 36"; middle: silty clay loam, depth to mottling 17"; bottom: silty clay, depth to mottling 7".

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surfaces may not be as detrimental as on coarser-textured soils (Figure 9).

Soil Chemical Characteristics

Although specific information is not available for desirable soil levels for the Canaan Valley seed source of balsam fir, average levels shown in Table 1 for soil pH, phosphorus, potassium, calcium, and magnesium in the A_p horizon would be adequate for most of the Christmas tree species grown in Ohio, including the more demanding spruces, firs, and Douglas-fir. However, standard deviations and ranges in values indicate that there were plots that were well below acceptable levels for all nutrients. There were significant positive relationships between some tree characteristics and phosphorous, calcium, and magnesium levels, but not for potassium (Table 2).

Cation Exchange Capacity (CEC) of soils on plots showed a wide range and is generally closely related to differences in soil textures discussed previously and particularly to clay in the A_p and B_2 soil horizons (Table 1).

Foliar Nutrient Levels

As noted for soil chemical characteristics, specific information is not available for desirable levels of foliar nutrients in trees for the Canaan Valley source of balsam fir. However, average levels for the major nutrients (N, P, K, Ca, Mg) shown in Table 1 are generally within the "adequate" range reported for Fraser fir *(A. balsamea* var. *fraseri)* (Huckins, 1996) and a northern source of balsam fir *(A. balsamea* var. *balsamea)* (McEvoy, 1992). However, there was a wide range in levels for trees on individual plots, with values ranging from well below to well above acceptable levels. For the micronutrients, average levels for all elements except copper were generally within the "adequate" level for Fraser fir (no data for balsam fir), with the range from well below to well above the "adequate" level (Table 1).

As shown in Table 2, there were positive, statistically significant correlations between foliar nitrogen levels and total height and all needle characteristics of trees. There were also significant relationships between foliar potassium levels and all tree characteristics which is of interest because no correlations were noted for soil potassium levels. None of the tree variables were significantly related to phosphorus levels, while there were significant relationships of calcium levels with total height, needle retention, needle length, and foliage weight.

Multiple Regression Relationships Between Tree Characteristics and Site Factors

Based on the previous results and correlation analyses, multiple regression analyses were made in an attempt to develop statistical "models" that would combine various site factors (soils and management) to evaluate multiple effects on growth and foliage characteristics of trees. As with correlation analyses, these equations assume linear relationships and do not imply direct cause and effect. A summary of those "models" is given in Table 3.

Of all the site factors measured/evaluated, only six were statistically significant in one more of the individual equations, with depth to mottling in the soil, slope shape, and sand in the A horizon occurring in four, thickness of the A_p soil horizon and slope percent in two, and sand in the B horizon in one. In all equations, coefficients for individual site factors were positive, indicating that survival, growth, and/or foliage characteristics of trees improved as slope shape went from concave to convex and depth to mottling, thickness of the A_p soil horizon, sand in the A and B horizons, and slope percent increased (Table 3). All of these relationships are similar to those noted for simple correlations between site factors and individual tree characteristics.

None of the equations accounted for a high percentage of the total variation in tree characteristics, with only 29 percent for total height, 26 percent for four-year height, 20 percent for survival, and 17, 12, and 19 percent, respectively, for needle length, needle color, and foliage weight. Given these small percentages of

Table 3. Summary of Multiple Regression Analyses of Relationships Between Site Factors and Survival, Growth, and Foliage Characteristics of Trees.

Site Factor	Plot Survival[2]	Total Height[2]	4-Yr. Height[2]	Needle Length[2]	Needle Color[2]	Foliage Weight[2]
	Tree Characteristic					
Slope %			+	+		
Slope Shape	+	+	+		+	
Depth Mtl.	+	+	+			+
Thick. A_p Horiz.	+			+		
Sand A Hor.	+	+	+	+		
Sand B Hor.						+
Total Variation Acc. For, %	20	29	26	17	12	19

[1] Only those site factors that were statistically significant in multiple regression equations were included in the table.
[2] A + or a - sign indicates positive or negative relationships between individual site factors and survival or tree characteristics in the multiple regression equation.
[3] Percent of total variation (100%) accounted for by one to four factors in individual equations.

variation accounted for, it would be meaningless to use the equations to develop guidelines for predicting tree performance on sites having a range of soil and/or topographic conditions.

Correlations and Multiple Regression Relationships Between Foliar Nutrient Levels and Tree and Site Factors

Foliar nutrient levels in the needles of trees are not "site factors" in themselves but rather are a reflection of a number of different factors, including soil levels of individual elements, influences of site factors where trees are growing, and, ultimately, in many cases the overall vigor of the trees themselves. As discussed earlier, average foliar nutrient levels in needles of trees on sample plots were generally at or above those levels needed for good growth and foliage characteristics of trees of most Christmas-tree species, including balsam and Fraser fir, with levels on individual plots from well below to well above desirable levels. To look more closely at influences on foliar nutrient levels, correlation and multiple regression analyses were used in attempts to relate foliar levels of five elements — nitrogen, phosphorus, potassium, calcium, and magnesium — to various combinations of soil, site, and tree characteristics. Summaries of those analyses are shown in Tables 4 and 5.

For nitrogen, potassium, and calcium, there were significant, positive correlations between foliar levels and most tree characteristics, reflecting higher levels in more vigorous trees. The correlations with foliar potassium were particularly strong. As discussed previously, specific information is not available for desirable soil nutrient levels for "Canaan" fir, although average soil and foliar potassium levels were generally adequate for most Christmas tree species, including Fraser fir. From data in this study it is not clear if the strong relation-

Table 4. Simple Correlations Between Foliar Nutrient Levels and Tree and Soil Factors for Plots Having "Effective" Chemical Weed Control.

	Foliar Nutrient				
Site/Tree Factor[6]	Nitrogen	Phosphorus	Potassium	Calcium	Magnesium
	Simple Correlation Coefficient, r				
Tree Factors					
Total Tree Height	0.35[5]	0.11[1]	0.60[5]	0.28[3]	0.01[1]
4-Year Height	0.16[1]	0.11[1]	0.57[5]	0.11[1]	-0.03[1]
Needle Length	0.59[5]	-0.13[1]	0.35[5]	0.34[4]	0.00[1]
Foliage Color	0.31[4]	-0.01[1]	0.60[5]	0.04[1]	-0.04[1]
Foliage Weight	0.37[5]	-0.18[1]	0.22[2]	0.25[2]	0.01[1]
Soil Physical Factors					
Depth to Mottling	0.38[5]	-0.09[1]	0.21[2]	0.37[5]	0.06[1]
A Horizon Sand	0.08[1]	0.36[5]	0.38[5]	0.05[1]	0.04[1]
A Horizon Clay	-0.21[2]	-0.39[5]	-0.18[1]	-0.22[2]	-0.11[1]
B Horizon Sand	0.18[1]	0.19[2]	0.30[4]	0.12[1]	0.09[1]
B Horizon Clay	-0.27[3]	-0.13[1]	-0.09[1]	-0.32[4]	-0.11[1]
Soil Chemical Factors					
A Horizon Phosphorus	0.08[1]	0.61[5]	0.28[3]	0.30[4]	0.23[3]
A Horizon Potassium	0.21[2]	0.20[2]	0.38[5]	0.11[1]	-0.26[3]
A Horizon Calcium	-0.11[1]	0.04[1]	-0.05[1]	-0.09[1]	-0.02[1]
A Horizon Magnesium	-0.21[2]	0.04[1]	-0.02[1]	-0.21[2]	0.09[1]
B Horizon Phosphorus	-0.13[1]	0.33[4]	-0.05[1]	0.06[1]	0.13[1]
B Horizon Potassium	0.18[1]	0.26[3]	0.27[3]	0.04[1]	-0.13[1]
B Horizon Calcium	-0.10[1]	0.17[1]	0.03[1]	-0.06[1]	0.06[1]
B Horizon Magnesium	-0.11[1]	0.23[3]	-0.03[1]	-0.16[1]	0.06[1]

[1] Not statistically significant.
[2] Statistically significant at the 10 percent probability level.
[3] Statistically significant at the 5 percent probability level.
[4] Statistically significant at the 1 percent probability level.
[5] Statistically significant at the 0.1 percent probability level.
[6] Only those variables for which correlations were statistically significant with one or more tree or site factors are included.

Table 5. Summary of Multiple Regression Analyses of Relationships Between Foliar Nutrient Levels (Nitrogen, Phosphorus, Potassium, Calcium, and Magnesium) and Soil Physical, Soil Chemical, and Total Tree Height.

	Foliar Nutrient				
Site/Tree Factor	Nitrogen[2]	Phosphorus[2]	Potassium[2]	Calcium[2]	Magnesium[2]
Total Tree Height	+		+	+	
Depth Soil Mottling	+	+		+	
A Horizon Sand	+		+		
A Horizon Clay	-	-	-	+	
B Horizon Sand	+		+		
B Horizon Clay		-	-	+	+
A Horizon Phosphorus	+	+			-
A Horizon Potassium	+	+	+		
Total Variation Accounted For, %[3]	31	53	54	22	12
Variation Accounted for by Tree Height, %[4]	4	3	35	5	1

[1] Only those tree or soil factors that were statistically significant in one or more multiple regression equations were included in the table.
[2] A + or a - sign indicates positive or negative relationships between individual tree or soil factors and foliar nutrients in multiple regression equations.
[3] Percent of total variation (100%) accounted for by one to seven factors in individual equations, including total tree height.
[4] Percent of total variation accounted for by total tree height only.

ship between foliar potassium and growth and foliage quality of trees is reflective of higher potassium requirements (Table 4).

For soil physical factors, correlations with foliar element levels were generally strongest for factors which would be indicative of better drainage conditions. Nitrogen levels showed relatively low correlations, with only A horizon potassium (positive) and magnesium (negative) being statistically significant at the 10 percent probability level. This is not particularly surprising since foliar nitrogen may be more reflective of soil organic matter levels and/or atmospheric input rather than soil elemental levels (Table 4).

Foliar phosphorus and potassium showed very strong relationships with soil levels of the two elements, particularly in the A horizon; this is encouraging because it may indicate that recommendations for phosphorus and potassium fertilization based on soil tests will be reflected in higher levels in the foliage. There were also statistically significant relationships between foliar phosphorus and soil potassium levels in the A and B horizons and magnesium in the B horizon and foliar potassium with soil phosphorus in both the A and B horizons. Conversely, statistical relationships between foliar calcium and magnesium with soil levels were very low (Table 4).

Using the correlations discussed previously, a series of multiple regression equations were developed to test relationships between foliar nutrients as dependent variables and tree, soil physical, and soil chemical factors. As shown in Table 5, only the equations for phosphorus and potassium accounted for over half of the total variation in foliar levels; for potassium, 35 percent of that variation was associated with total tree height, the only statistically significant tree factor in any of the equations, which, as discussed previously, is in itself a measure of tree vigor. As a result, as discussed for the regressions between tree and site factors, it would be meaningless to use the equations in an attempt to develop guidelines for improving foliar nutrient levels of trees.

Guidelines for Choosing Planting Site

Because of the diversity of the data collected from study plots and the complex interrelationships between many of the site factors, it was not possible to develop useful multiple regression equations which could be used for choosing sites and predicting survival and growth of the Canaan Valley seed source of balsam fir. However, the correlation and regression analyses, plus observations and measurements from individual plots, provide good insights into the response of trees on a wide variety of sites. Based on that information, the author believes that the "Qualitative Planting Guide" presented in Table 6 should provide a basis for choosing sites and estimating performance of trees planted on a wide variety of sites. Many Christmas tree growers may need help to determine/evaluate some of the factors, such as depth to mottling and soil texture, which are included in the table. County soil surveys provide excellent, detailed information for "soil mapping units" down to approximately two acres in size but may not identify smaller inclusions having soil characteristics that could affect survival, growth and/or foliage quality of trees. Individual soil maps developed by the USDA Natural Resources Conservation Service or commercial soil scientists for growers' plantation areas can provide more detailed information about specific sites.

Conclusions and Recommendations

Results of this study point out the complex nature of the interactions between survival, growth, and foliage quality of trees of "Canaan" fir and various combinations of plantation management, topographic, and soil factors (Figure 10). Weed control that effectively reduces the density of vegetation can be critical to survival, growth, and foliage quality of trees. On plots evaluated in this study, use of residual herbicides for at least the first four years after trees were planted, in combination with mowing, provided effective control of herbaceous vegetation. An earlier study (Brown *et al.*, 1989) showed the benefits of annual applications of herbicides over a six-year period, particularly to Fraser fir, Douglas-fir, and Colorado spruce (but less so to Scotch pine and white pine). Another study (Brown, 1980) detailed the benefits of vegetation removal/reduction and showed that use of herbicides and mechanical removal (shallow tillage), which kept herbaceous vegetation out of plots, were equally effective. A third study (Heiligmann *et al.*, 1985) found that control of vegetation in strips along rows of trees and applications of herbicides to the whole planting area were equally beneficial to survival and growth.

Fertilization, particularly with nitrogen, can also enhance foliage quality of trees. For trees in this study, evaluation of the effects of fertilization was difficult because of the limited number of trees fertilized and the variety of combinations of materials and frequencies of applications used. In a study at OSU/OARDC, nitrogen fertilization was effective in improving foliage quality of trees (but not growth) of "Canaan" fir growing on a variety of sites, all of which received annual applications of herbicides (Brown, 1998). In another study, nitrogen fertilization was beneficial to trees of "Canaan" fir, Colorado spruce *(Picea pungens)*, and Scotch pine *(Pinus sylvestris)* on plots where chemical weed control was used in combination with mowing, while growth and foliage quality of trees was poorer on plots which were fertilized without chemical weed control than on plots having chemical weed control only (Brown, 2000).

Table 6. Guidelines for Choosing Sites for Planting of Trees of the Canaan Valley Seed Source of Balsam Fir.

Aspect[1]	Slope Pos.[2]	Total Soil Depth (in.)	Depth Soil Mottling (in.)	Soil Texture[3]	Slope Shape[4]	Planting Site Suitability[5]
Upland Sites With Slopes Over 15%						
SW	Upper	<20	NA	All	All	N
		>20	NA	Crse	All	L-N
		>20	NA	Med-Fine	All	L
SW	Lower	<20	NA	Crse	All	L-N
		<20	NA	Med-Fine	All	L
		>20	NA	Crse	All	L-S
		>20	NA	Med-Fine	All	S
NE	Upper	<20	NA	Crse	All	L
		<20	NA	Med-Fine	All	L-S
		>20	NA	Crse	All	L-S
		>20	NA	Med-Fine	All	S
NE	Lower	<20	NA	Crse	All	L-S
		<20	NA	Med-Fine	All	S
		>20	NA	All	All	S
Gently Sloping Areas (5 to 15%)						
All	All	>20	>20	Crse	All	L-S
All	All	>20	>20	Med-Fine	All	S
All	All	>20	10-20	Crse-Med	All	S
All	All	>20	10-20	Fine	All	L-S
All	All	>20	5-10	Crse-Med	All	L-S
All	All	>20	5-10	Fine	Cnvx	S
All	All	>20	5-10	Fine	Cncv	L
All	All	>20	<5	Crse	All	L-S
All	All	>20	<5	Med-Fine	Cnvx	L
All	All	>20	<5	Med-Fine	Cncv	N
"Flat" Bottomland Sites (Slopes <5%)						
All	All	>20	>20	All	All	S
All	All	>20	10-20	Crse-Med	All	L-S
All	All	>20	10-20	Fine	Cnvx	L-S
All	All	>20	10-20	Fine	Cncv	L
All	All	>20	5-10	Crse-Med	All	L-S
All	All	>20	5-10	Fine	Cnvx	L
All	All	>20	5-10	Fine	Cncv	N
All	All	>20	<5	Crse	All	L
All	All	>20	<5	Med-Fine	Cnvx	L-N
All	All	>20	<5	Med-Fine	Cncv	N

1 Aspect: Southwest = Clockwise from 135 to 315 degrees; Northeast = Clockwise from 315 to 135 degrees. Aspect effects are generally negligible on slopes less than 15%.
2 Slope position effect (upper or lower) is generally negligible on slopes less than 15%.
3 Soil Textural Classes: Coarse = Sand to Fine Sandy Loam; Medium = Very Fine Sandy Loam to Silty Clay Loam; Fine = Sandy Clay to Clay.
4 Slope Shape: Cnvx = Convex; Cncv = Concave.
5 Planting Site Suitability: S = Suitable: Growth and foliage quality should be good to excellent; L = Limited Suitability: Species will probably grow and produce marketable trees on sites but establishment problems may be greater and growth and foliage quality reduced; N = Not Suitable: Survival, growth, and/or foliage quality will probably be so impaired that species should not be planted.

Figure 10: Worst possible combination of lack of effective weed control, fine-textured soils, and concave-shaped (front) and convex-shaped (back) surface configurations.

Results of the study show that trees of the Canaan Valley seed source of balsam fir can survive, grow, and produce marketable Christmas trees on a wide range of sites, including many somewhat "wetter" areas where Fraser fir and Douglas-fir *(Pseudotsuga menziesii)* do not do well. It was not possible to develop useful multiple regression equations which could be used to develop planting guides for choosing sites and predicting survival and growth of the Canaan Valley seed source of balsam fir. However, the correlation and regression analyses and observations from individual plots do provide good insights into response of trees to a wide variety of site conditions. As with essentially all Christmas-tree species, tree performance was best on "moist" but not "wet" sites on north- and east-facing slopes and on medium-textured, well- to moderately well-drained soils. On finer-textured soils where surface drainage was good, growth and foliage quality were generally somewhat poorer but still acceptable for producing marketable trees. On concave-shaped, gently sloping to bottomland sites which were somewhat-poorly to poorly drained, survival, growth, and/or foliage quality of trees was generally below acceptable levels on finer-textured soils but acceptable on coarser-textured loams to sandy loams which were usually associated with seasonally high water tables. Based on the statistical analyses and in-the-field observations and measurement, the author believes that the "Qualitative Planting Guide" (Table 6) developed from results of the study should provide good information for choosing sites and estimating performance of trees of "Canaan" fir planted on a wide variety of areas.

The average soil nutrient levels found on study plots appear to be adequate for good growth and foliage quality of trees, with the values of 59, 198, 1,710, and 277 pounds per acre, respectively, for phosphorus, potassium, calcium, and magnesium being equal to or above those reported as being adequate for other higher quality trees such as Douglas-fir, Fraser fir, and more northerly sources of balsam fir. Average foliar levels of 1.85, 0.22, 0.83, 0.59, and 0.14 percent, respectively, for nitrogen, phosphorus, potassium, calcium, and magnesium were also at or above those reported as being acceptable for good growth and foliage quality of the same Christmas tree species.

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